National Aeronautics and
Space Administration

Electronic Parts and Electrostatic Discharge (ESD) – Gaps and Mitigation Strategies Updates

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After a Reset, Curiosity Is Operating Normally

NASA's Curiosity Mars took this image with its Mastcam on Feb. 10, 2019 (Sol 2316). The rover is currently exploring a region of Mount Sharp nicknamed "Glen Torridon" that has lots of clay minerals.

Credits: NASA/JPL-Caltech/MSSS

Electronic Parts and Electrostatic Discharge (ESD) – Gaps and Mitigation Strategies

- Gaps have evolved because of new technology and inconsistencies of standards development (e.g., three zaps vs. one zap per pin for testing). Parts have continued shrinking to smaller sizes & growing in complexity. Consequently, they are more susceptible to ESD and require more testing effort.
- Costs cannot be ignored—per unit price for advanced devices is approaching $200K. ESD mitigation costs are minute compared to the device unit costs.
- Mitigation strategies include ESD surveys, observations during audits, standards updates (including harmonization of standards), & outreach to the military & space communities.

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Why Electronic Parts and ESD Need a Fresher Look--Gaps

- NASA has been supporting Defense Logistics Agency (DLA) audits of the supply chain.
- During the audits, it was observed that the MIL-PRF-38535 requirements were practically nonexistent regarding ESD aspects of electronic parts.
- Microcircuit pin count has increased significantly (e.g., Vertex FPGAs have 1752 columns). Manufacturers are striving for still higher counts.
- Current qualification standards were developed years ago with pin counts in the twenties.
- Applying these old device testing standards to modern high-pin count products can cause severe problems (e.g., testing times increase dramatically).
- Furthermore, microcircuit part production is no longer under one roof, but landscape of supply chain is multiple specialty houses (see next slide).

Need to update standards

A Changing Landscape (Shipping/Handling/ESD Challenge)

A New Trend – Supply Chain Management
Ensuring gap-free alignment for each qualified product
(All entities in the supply chain must be certified/approved)

Manufacturer A	Die design
Manufacturer B	Fabrication
Manufacturer C	Wafer bumping
Manufacturer D	Package design and package manufacturing
Manufacturer E	Assembly
Manufacturer F	Column attach and solderability
Manufacturer G	Screening, electrical and package tests
Manufacturer H	Radiation testing

More Stops — More Places with ESD Risk

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Activities to Improve ESD and Electronic Parts (1 of 2)

- **DLA Conducted Engineering Practice (EP) Study on ESD**
  - EP study is a survey of manufacturers, users and other interested entities
- **JC-13 Started a Task Group on ESD (Chair: P. Coe of Cobham, Colorado Springs, CO)**
  - The fact that it is a JC-13 task group means that it has the highest level of attention and applies to all commodities
  - The task group is already active
- **JEDEC/ESDA Are Continuing Joint Effort**
  - JESD 625B and S20.20 Harmonization telecons and face-to-face meetings
  - Participation by NASA and Aerospace Corporation

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Activities to Improve ESD and Electronic Parts (2 of 2)

- **Updated MIL-STD-883, Test Method 1014**
  - Added Para 2.2.1d. “ESD Protective Tubes shall be utilized to ensure the system is ESD safe…”
- **Added requirement in 38535K for post column attach electricals**
  - To catch handling/ESD related problems
- **Continuing NASA ESD Surveys**
  - Conducted by NASA experts

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NASA ESD Surveys of Microcircuit Supply Chain

- **NASA ESD Surveys**
  - Benefits not only NASA but the whole community
    - Especially vendors processing very expensive new technology parts (where the **per unit price could approach $200k)**
  - Candidate companies are identified during DLA audits—but not a DLA activity
  - Conducted by NASA ESD experts
    - The survey findings and corrective actions have been merely suggestions for improvements (but, in all cases, were implemented by the vendors)
  - Very well received
    - Some vendors have requested re-surveys every two years
  - Working with Suppliers and DLA to incorporate NASA ESD Surveys into DLA audit agendas
    - Make efficient use of resources
    - Was done a few times, worked well

NASA ESD Surveys of Manufacturers and Supply Chain

- **NASA ESD Surveys (FY2018)**
  - Manufacturers Surveyed
    - ❖ Concurrently with DLA audits: 2 (both have Q, V, & Y certifications)
      - ➢ Teledyne-e2v, Grenoble, France
      - ➢ Cobham, Colorado Springs, CO
    - ❖ Outside of their DLA audits: 4
      - ➢ Microsemi, San Jose, CA (QML Q and V)
        - ✓ Offering popular FPGA, RTG4
      - ➢ DDC, San Diego, CA (Formerly, Maxwell) QML Q and V
        - ✓ Moved to a different location in the area
      - ➢ Anaren, Syracuse, NY (Formerly, MS Kennedy) QML H, K, Q and V
        - ✓ Multi-center usage, delivery issues/new operators
      - ➢ Q-Tech, Culver City, CA (QPL B and S)
  - Supply Chain Surveyed: 3
    - ❖ Kyocera, San Diego, CA (Q, V, Y for assembly and test)
    - ❖ Micross, Orlando, FL (Q, V for assembly and test)
      - ➢ Building rad hard space Ferro-electric random access memories (FRAMs) for Cypress
    - ❖ Micross, Raleigh, NC (Q, V and Y for column attach)
      - ➢ IBM-like columns

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Examples of NASA ESD Survey Findings

- **Findings**
  - ESD Protected Areas (EPAs) were not designated as such
  - There were non-ESD safe cabinets that needed shielding/grounding
  - In several cases, chairs were noted to be non-ESD Safe
  - Non-ESD items found on ESD work benches
    - ❖ Binders, plastic bottles, mouse pads
  - CRT monitors were found near parts in engineering test. These are charge generators. CRT displays are not recommended.
  - Cloth wrist straps were used typically. Prohibited per JPL 34906.
  - Operator retraining certifications had lapsed
  - Waste Bins/Bin Liners were found to hold or generate charge
  - PIND Test
    - ❖ Ionizers were needed to neutralize charge from sticky tape used to hold parts on transducer

Potential ESD Issue Identified During Customer Source Inspection (CSI)

- **Cleanroom Humidity Nonconformance**
  - A customer source inspection (CSI) was performed recently
  - During the routine check of temperature and relative humidity in the cleanroom, humidity was seen to be 26.5%
    - ❖ Mil spec requires 35-65%
  - The manufacturer to notify DLA of their nonconformance
  - Further follow-up thru NEPAG
    - ❖ NASA ESD Survey
    - ❖ Other (TBD)

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Device Design Enhancements – An Ongoing Process

- **A major manufacturer is currently enhancing ESD protection networks**
  - To improve thresholds for HBM and CDM
  - To get higher yields
  - Four devices affected
  - Qualification data being reviewed by microcircuits Qualifying Activity (QA) which includes DLA, The Aerospace Corporation and NASA

ESD Outreach by NASA

- **NASA Is Highlighting ESD in *EEE Parts Bulletins***
  - Released three special editions on ESD.
  - The first dealt with the need to upgrade specifications related to ESD and suggestions for better ESD practices wherever parts are manufactured, stored, or prepared for shipment.
  - The second ESD special issue focused on a parts failure investigation that ultimately concluded that ESD was the most likely cause of the failure. The second issue also included an important reminder about regular ESD testing.
  - The third issue provided an example demonstrating the importance of maintaining ESD discipline and a high-level risk analysis related to electrostatic discharge.

- **Invited ESD Talks**
  - NASA has been instrumental in arranging invited talks at JC-13/CE-12 meetings.

MIL-PRF-38535 Revision L, Dated December 6, 2018

- **ESD Changes Summary**
  - Para 2.3. Updated HBM, added CDM
  - Para 3.2.1. Added S20.20 as an alternate
  - Para 3.12. Updated program control requirements
  - Para 3.6.7.2. Updated sensitivity identifiers for HBM, added CDM
  - Para 4.2.3. Updated ESD requirements
  - Para A.3.4.1.4. Updated references
  - Para A.3.6.9.2. Updated test requirements
  - Para 4.4.2.8. HBM update
  - Table H-IIA. Updated HBM reference
  - Table H-IIB. Updated HBM reference

  - These changes are a good step.

NASA Comments

- **MIL-PRF-38535 Rev L**
  - This revision is a good start. But, there are
    - ❖ No specific requirements for wafer foundries
      - Suggested solution: Replace “Devices” with “Wafers/Dice/Devices” such as in Para A.4.4.2.8:
      - A.4.4.2.8 Electrostatic discharge (ESD) sensitivity. ……..Wafers/dice/devices shall be handled in accordance with the manufacturer's in-house control documentation, which shall be maintained by the manufacturer……...
    - ❖ Add requirements for shipping and handling of products in multi-supply chain production of parts (which is becoming the norm).
    - ❖ Look into ESD behavior of high-speed pins

- **MIL-STD-883, Test Method (TM) 3015**
  - MIL-PRF-38535 Rev L calls out JS-001 as an alternate to 3015. Should compare the two and identify differences.
  - This TM should be updated

NASA ESD Mitigation Going Forward

- **Mitigate Existing and Possible Future ESD Issues by Supporting Efforts in Six Categories:**
  1. NASA ESD surveys
  2. Independent evaluations of new technologies (e.g., high speed and high power microcircuits, GaN devices, SiC devices). Characterization of ESD thresholds per Human Body Model (HBM) and Charged Device Model (CDM) for new devices
  3. Independent evaluations of 883 vs. JEDEC test method equivalencies for HBM
  4. Low-ESD-threshold parts mitigation, e.g., GaN, very high speed ICs (GHz range) -- conduct limited tests to make recommendations
  5. Interfacing with industry groups (e.g., JC13, JC14, ESDA, EC-11, EC-12)
  6. Harmonizing ESDA 20.20, JEDEC 625, and other ESD standards

- **Note: NASA Is Part of the Qualifying Activity (QA) for Space Microcircuits**

Summary

- NASA brought many ESD concerns to the attention of the parts community
- All types of commodities affected for both military and commercial parts
- COTS hardware could be affected more severely
- Monthly telecons are held on harmonization of 625 and 20.20 ESD standards
- NASA is continuing to conduct ESD Surveys
- 38535 Rev. L has updated ESD requirements
- Parts community must promote an ESD-safe environment!

- Be mindful of ESD when shipping / handling parts and hardware!

Backup Slides

- Resolving Major Issues Found During DLA Audits
- NASA ESD Surveys Are Meeting Greater ESD Challenges for Electronic Parts
- *EEE Parts Bulletin* ESD Special Issues

Resolving Major Issues Found During DLA Audits

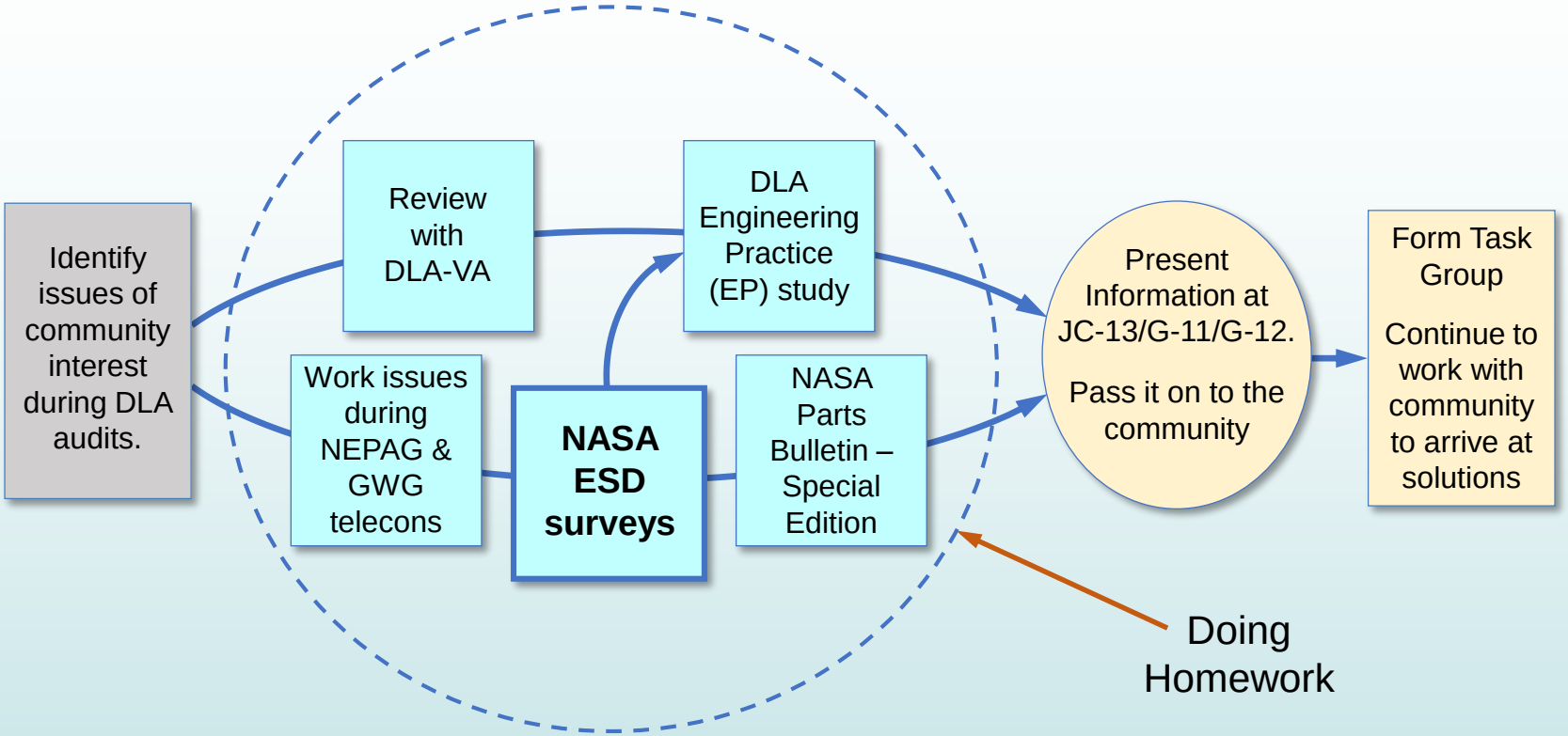
- **The Paths from Issues to Microcircuit Process Improvements**

- NASA, Aerospace Corporation, and other organizations often participate along with the Defense Logistics Agency (DLA) Land and Maritime personnel in DLA audits. The primary purpose of DLA audits is to get better electronic parts by monitoring compliance with the MIL specifications and by working with the manufacturers to enhance quality of their products.

- In addition, NASA has conducted electrostatic discharge (ESD) surveys of parts manufacturers. Those surveys produced recommendations regarding ESD mitigation and control. These recommendations are not enforced, but the surveyed companies all implemented the suggestions.

- However, as shown on the next slide, there is much more that comes from these audits and surveys. These visits help identify concerns and/or opportunities that are then addressed by other means. This is a path that has worked in resolving major issues found during the audits and surveys that may require community involvement. It may evolve or be adjusted over time.

NASA ESD Surveys Are Meeting Greater ESD Challenges for Electronic Parts



- Bring general awareness (Via NASA Bulletins, Surveys)
- Work with DLA to help them conduct an engineering practice (EP) study
- Generate a basic proposal and related information so the potential task group (TG) has a strong starting point.
- This path has **saved time** in resolving major issues found during audits.

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EEE Parts Bulletin Electrostatic Discharge Special Issue (Part 1)

- **NASA EEE Parts Bulletin (January – July 2016)**

National Aeronautics and Space Administration

EEE Parts Bulletin

Electrical, Electronic, and Electromechanical

A periodic newsletter of the JPL/OSMS Assurance Technology Program Office (ATPO), NASA EEE Parts Assurance Group (NEPAG), and Section 514, of the Jet Propulsion Laboratory.

January–July, 2016 · Volume 8, Issue 1, Revision A, January 26, 2017
Special Edition on Electrostatic Discharge (ESD)
(The NASA *EEE Parts Bulletin* has been published since 2009)

Note: This revision adds a number of details and corrects ambiguities in the original issue that was released August 31, 2016 (the K. LaBel article on partnering and the back-page material were not changed).

Damage from ESD is a major cost to the microcircuit industry in terms of time, money, and mission risk. We plan to release two issues. This first special issue deals with the need to upgrade specifications related to ESD and suggestions for better ESD practices wherever parts are manufactured, stored, or prepared for shipment. This issue also includes an article about partnering in radiation and reliability testing. The second special issue will describe examples of ESD-related problems. Figure 1 is an example of damage caused by ESD.

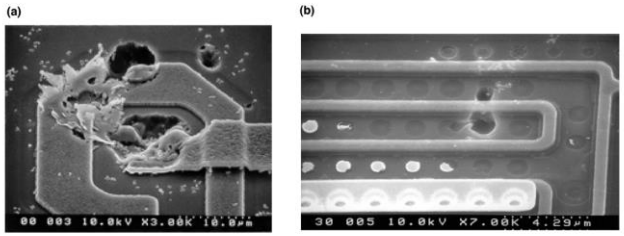

Figure 1. Examples of ESD damage to microcircuits (Images courtesy of JPL Analysis and Test Laboratory):
a) A static random access memory (SRAM) device with 5-micron features was deliberately exposed to an 8000-volt pulse from a 100-picofarad capacitor. This produced an approximately 5.3-ampere peak current pulse lasting just under one microsecond. Melting of conductive traces is typical of such ESD damage and creates an open circuit path.
b) An undefined microcircuit with 1-micron line widths that failed in service after being exposed to a pulse of approximately 500 volts. This caused a breakdown of the SiO_2 layer and a short circuit in the part.

Upgrading ESD Control: Its Importance and Possible Strategies

A. What Is ESD and How Are ESD Controls Applied?

Electrostatic discharge or ESD in electronic parts is an electrical sparking event that functions like a tiny version of lightning. When two objects with different potentials are brought sufficiently close, a current flows toward the ground equalizing the potential. These differences can be caused by friction of dissimilar materials (shoes on a carpet is a classic example), but even the difference in potential between a human body and an object may be enough to initiate an ESD event.

For electronic parts, built to carry minute amounts of current, tiny lightning bolts are a cause for concern. If such an errant current flow of an ESD goes along the outer case of a part or the outside of an ESD-resistant (anti-

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tatic) bag or shipper, there may be no problem. However, such a current goes through the part, serious damage may result. ESD damage can include catastrophic damage and/or latent damage. Catastrophic damage is immediately detectable by the resulting loss of function and often visible damage. Latent damage is not immediately detectable because there is no loss of function and often no visible sign of damage. However, the part has been weakened and may fail in the field or (worse) in space.

This has always been a serious concern for electronic parts, but it has grown steadily more urgent.

The purpose of this article is to sensitize the entire space community, and in particular, the standards-developing-bodies to the fact that the ESD requirements must be clearly specified in such standards documents so that everybody handling microcircuits, from manufacture to final use can minimize ESD damage. Furthermore, the standards must be updated to reflect the present level of technology.

In this context, the role of DLA (Defense Logistics Agency) for the department of defense (DoD) becomes vital. The standardization branch of DLA develops and maintains the military (MIL) standards, which are used for maintaining high-reliability quality parts production for the DoD and for NASA. In addition, manufacturers and non-MIL standards organizations provide inputs to the standards

These standards are often enforced by periodic audits of parts manufacturers and their supply chains. The audit branch of DLA officially conducts official enforcement. NASA actively supports DLA in both of these activities.

For the purposes of this article, we are focusing on monolithic microcircuits. The standard most commonly used by the U.S. space community for high-reliability microcircuits is MIL-PRF-38535, *Integrated Circuits (Microcircuits) Manufacturing, General Specification for*. Any microcircuit parts produced under the military system must be in compliance with the requirements of this document.

The 38535 is the periodically changing overall document controlling microcircuit quality and reliability. The ESD aspects of the document clearly need updating. For auditing, the requirements must be flowed down to the working audit, and it must be reflected in each manufacturer's quality management (QM) plan.

In addition, the ESD-related standards used by other organizations may provide ideas for upgrades to the MIL standards. Conversely, it would be highly beneficial if the MIL standard upgrades could be coordinated with those of the other standards bodies so that practices throughout the industry might be as similar and interchangeable as possible.

B. Why Improved ESD Control Practices Are Crucial

Microcircuit densification has increased pin counts significantly in the last decade, particularly for communication and computing products. NASA and the space community are using 1752-pin counts, and higher counts are growing more common in the general market.

Current ESD rating methods were developed with typical pin counts in the twenties. Applying these old device testing standards to modern high-pin count products can cause severe problems. Testing times increase dramatically. Worse, wear caused by repeatedly stressing the same path and the increasing influence of tester parasitic losses (parasitics) can lead to false-positive failures.

The increased capabilities attained by increasing parts density has come at the cost of greater sensitivity to ESD. Thus, it becomes increasingly important to implement better methods of controlling potential damage from ESD. A wide assortment of books and journal papers provides information on methods for mitigating ESD.

For high-reliability microcircuits (where a part may cost as much as tens of thousands of dollars), organizations often develop and enforce required policies and procedures designed to mitigate ESD. These policies and procedures are codified in standards.

Furthermore, the landscape of microcircuit part production, handling, and shipping has changed radically. Because of the increased complexity of parts, the paradigm of a manufacturer shipping directly to a customer has largely given way to a highly dispersed production environment, which in turn, often requires highly dispersed ESD control among a number of organizations. Table 1 shows all the steps at which production or use of a microcircuit might be done by shipping to another facility. (The most extreme cases of maximum dispersion are more likely with new products such as flip chips.) Moreover, each of the steps involves at least one environment each for working on the part, storing the part, and shipping the part to the next step in the production.

Much as increased pin counts increase the susceptibility to ESD, increasing the number of shipping steps in the supply chain increases the number of points where ESD damage may occur.

It is important to recognize and fully address all the risk points to which ESD sensitive parts are subjected: from when they are fabricated and delivered from the original component manufacture's (OCM) site; through supply chain avenues to user inventories; then on to kitting and upper-level printed circuit board (PCB) level assembly, test and verification; and eventually to final box level assembly, test and final system level test. This is particularly important for handling, packaging, and shipping of ESD Class 0A devices (<125 volts in the Human Body Model).

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models?: Those models are 1) human body model (HBM) based on people accumulating electric charges; 2) charged device model (CDM) based on materials becoming charged after they rub against other materials; and 3) machine model (MM) [designed to simulate a machine discharging through a device to ground].

- Do we want a standard for reducing the number of pin combinations required for testing?
- Would statistical pin testing be a good approach?
- How can the testing time be reduced without losing useful information (and significantly impacting the test data)?
- Should the MIL standards be expanded to include charged device model (CDM) testing?
- How do the new 2.5D and 3D configurations affect ESD testing?

We need to consider future trends when revising test standards. This issue is growing more important because the unit cost of contemporary devices are very high (and are growing costlier as more functionality is added), on the order of several tens of thousands of dollars per unit. Poor ESD environment for such products creates possibility of damage/ latent damage to them, both of which could be very expensive. Costs for implementing an ESD-prevention program are miniscule compared to the overall cost incurred in dealing with ESD damage.

The above concerns were presented by NASA representative Michael Sampson at the June 2016 G12 Space Subcommittee meeting. He proposed that the military documents that control the ESD requirements for testing and rating ESD event severity be reviewed and updated as a first step. As part of this update process, he suggested that Defense Land and Maritime (DLA), which serves as the qualifying authority to maintain the MIL system of parts qualification, perform an engineering practice (EP) study on ESD to detail these issues and compare possible specification changes with those being implemented or proposed by other organizations, in particular the NASA Inter-Agency Working Group related to ESD (NASA IAWG-ESD). Ideally, coordination among the various standards-setting organizations would result in updated ESD standards with a great deal of commonality. DLA shared the results of their EP study at the JEDEC meeting held in January 2017. Based on the EP study and responses to it, JEDEC (JC-13) has opened a task group to resolve issues related to ESD.

These document changes will require review and coordination with associated reference documents from other organizations to bring consistency.

- Are all three commonly used ESD models still valid or should the standards focus on one or two

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EEE Parts Bulletin Electrostatic Discharge Special Issue (Part 2)

- **NASA EEE Parts Bulletin (August 2016 – May 2017)**

National Aeronautics and Space Administration

EEE Parts Bulletin

Electrical, Electronic, and Electromechanical

A periodic newsletter of the NASA Electronic Parts Program / NASA EEE Parts Assurance Group and the Jet Propulsion Laboratory

August 2016–May 2017 • Volume 9, Issue 1 (Published since 2009), June 16, 2017

Second Special Edition on Electrostatic Discharge (ESD)

Damage from ESD is a major cost to the microcircuit industry in terms of time, money, and mission risk. The first issue dealt with the need to upgrade specifications related to ESD and suggestions for better ESD practices wherever parts are manufactured, stored, or prepared for shipment. This second ESD special issue focuses on a parts failure investigation that ultimately concluded that ESD was the most likely cause of the failure. The issue also includes an important reminder about regular ESD testing and a table of standard microcircuit drawings that were recently reviewed,

Figure 1 is an example of damage that was probably caused by ESD.

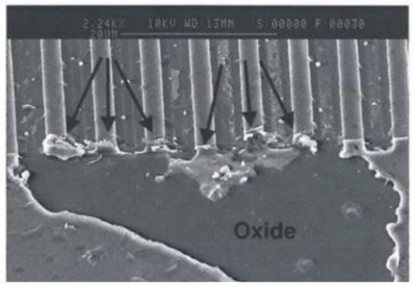

Fig. 1. Detailed view of a damaged site on a metal oxide semiconductor field-effect transistor (MOSFET) probably caused by ESD.

ESD, the Silent Killer—

A. Background

There are several great points to consider with respect to ESD knowledge, practice, and compliance. However, the key for ESD program success is consistency. If we detect the results of an event, then, we [the operational group] should be able to ascertain and confirm that we never have any lapses in the program implementation. With systematic practices, we should be able to surmise that there is no way any events can occur on the organizational project watch.

ESD is the silent killer in electronics, and the resulting impacts are hidden project costs that are the motivator to address project risk cost and schedule impacts. When an ESD event occurs, one of three scenarios may play out.

1) There is no impact, and no detrimental result.

2) There is a catastrophic strike and the immediate

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...failure is detected, isolated, ...irs may be easy or done at ...hey are done.

...le event may happen. Unde... ...e or more parts results in la... ...are either detected during ...ns or (worse yet) during mis... ...en any resulting failures may

...pens in the product life cycle ...e project cost for repair. La... ...ion is weak due to lack of ac... ...malfunctioning hardware for

...we need the highest possible ...D program compliance at all ...ctive.

...nly include part costs, which ... (for a typical active part) to ...programmable gate arrays, ...labor and mission assurance ...real hidden costs can poten... ...ring the diligence to complete ...failure analysis, possibly nu... ...eview boards and completion ... disposition of the ESD failure

...alone associated with all the ...uthorities, subject matter ex... ...vare assembly personnel at... ...tings can in most cases out ... of the damaged part alone. ...o participate in system tear... ...part screening/testing of the ...e new part, reassembly, and ...em. Therefore, prevention is

...of some metallic oxide semi... ...stor (MOSFET) devices that ...assembly of a recent space ...tion (ISS) support instrument ...d, in ESD protective packag... ...ard-level assembly soldering ...d-assembly-level verification ...ting ruled out design or oper... ational issues. The suspect parts were removed, tested, and shipped off for failure analysis.

Figure 2 shows the PCB assembly with two noted nonfunctional parts circled in red. Although not conclusive, the corner location of damaged parts on the board was thought to be important to the forensics analysis. One theory implied that handling of the board (by the perimeter) allowed for the ESD event to contact these parts directly. During transport, the board is handled only inside an ESD-approved materials bag. There were questions as to the integrity of these transport bags. Due to bag traceability and reuse issues, there was no definite conclusion on this concern.

Figures 3 thru Figure 7 Show the die and damage areas from various photographic and radiographic perspectives. During upper-level assembly circuit troubleshooting, the potential for design or operational damaging voltages to the MOSFET gates were conclusively ruled out. The circuit was incapable of generating the necessary damaging voltages that would have the effect observed.

C. Investigation Conclusion

The conclusion of this ESD failure investigation was that failure was attributed to user error but review of all ESD compliance logs showed that all precautions were taken during operator handling. Due to lack of further evidence, the OCM and the PCB assembly operation were not ruled out as possible culprits, but neither could be confirmed.

Under these circumstances the team was advised of the event and warned of the total cost for repair and the need to double check all future handling procedures. The board was repaired with same lot date code parts, and there were never any repeat operational issues with that PCB assembly nor at the box operational level. The "Silent Killer" only struck once on that program. At least as far as can be determined at this time.

Figures 1 through 7 (provided courtesy of NASA Langley Research Center) were generated by Hi-Rel Labs as part of a project Component Failure Investigation at Langley.

For more information, contact

John E. Pandolf 757 864-9624

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...circled in red.

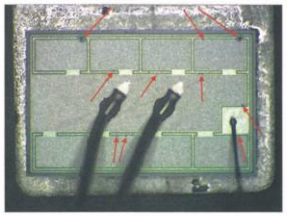


Fig. 3. Optical micrograph of the die in the failed device. The red arrows indicate the damage sites.

...damage sites on the die.

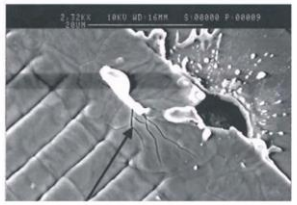
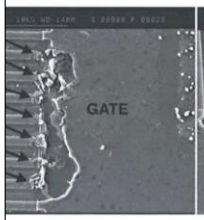
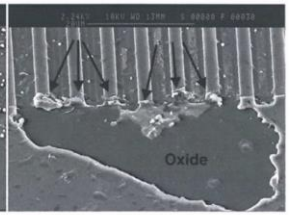


Fig. 5. SEM image of one of the damage sites. The arrow indicates the area where the damage originated





...ET after delayering. The arrows indicate the damage at the ends of the gate runners.

Fig. 7. SEM image of another damaged area on the die. Note that the gate polysilicon fused during the failure, which is why the oxide is visible.

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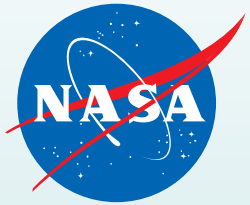
http://nepp.nasa.gov



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